# 桔小实蝇抗敌百虫品系的实验种群生物学比较研究

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**摘要：**【目的】研究明确桔小实蝇 *Bactrocare dorsalis* (Hendel) 抗药性品系与敏感品系的基本生物学特征以及相对适合度、内禀增长率等种群生物学参数差异。【方法】实验室条件下筛选出对敌百虫具中抗和高抗的桔小实蝇品系，观察记录其与敏感品系的生物学特性，比较三者之间的主要生物学参数。【结果】桔小实蝇敏感品系与 2 个抗性品系的卵、幼虫和蛹的发育历期、化蛹率、产卵前期、雌雄虫寿命、存活时间及雌虫比率均无显著差异。中抗品系卵孵化率和成虫羽化率分别为 68.33% 和 93.73%，均显著低于敏感品系(分别为 88.33% 和 97.93%)和高抗品系(分别为 86.67% 和 98.21%)。与敏感品系的产卵量 864.61 粒/雌和高抗品系的产卵量 750.70 粒/雌相比，中抗品系的产卵量降低至 630.87 粒/雌。3 个品系雌虫日产卵量动态规律比较一致，均呈开始产卵后短时间内进入产卵盛期，继而产量达到高峰，之后产卵量波动下降。但是与敏感品系相比，2 个抗性品系雌虫较早进入产卵高峰。对成虫存活率动态拟合方程参数 c 值均大于 1，符合 I 型存活曲线基本模型，表明在实验室理想条件下 3 个品系成虫均能达到其平均寿命。敏感品系种群趋势指数($I$)最高，为 339.41，其次为高抗品系($I$ = 307.82)，最小为中抗品系($I$ = 175.79)，表明对敌百虫产生抗性抑制了桔小实蝇种群的增长，中抗品系抑制程度更大。敏感和高抗品系实验种群净增殖率较高，分别为 327.89 和 284.29；中抗品系显著较低，为 217.49。2 个抗性品系内禀增长率($r_m$)和周限增长率($\lambda$)间无显著差异，且均显著大于敏感品系，世代历期($T$)则显著缩短。基于种群净增殖率获得的敌百虫高抗和中抗品系相对适合度分别为 0.8670 和 0.6633。【结论】在敌百虫的选择压力下，桔小实蝇抗药性品系的世代周期、中抗品系卵的孵化率和蛹的羽化率显著降低，其他多项生物学特征无显著变化。抗性品系的繁殖力和种群世代增长量受到抑制，以中抗品系更为明显；但与敏感品系相比，抗性品系种群增长潜力更大。

**关键词：**桔小实蝇；抗药性；敌百虫；生物学；生命表

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# A comparative study of the population biology of trichlorfon-resistant strains of the oriental fruit fly, *Bactrocera dorsalis* (Diptera: Tephritdae)

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**Abstract:**【Aim】This study aims to clarify the difference in basic biological characteristics and population parameters like relative fitness and intrinsic rate of increase, between different trichlorfon-resistant strains and susceptible strain of the oriental fruit fly, *Bactrocera dorsalis* (Hendel).【Methods】The high- and medium-level trichlorfon-resistant strains of *B. dorsalis* were selected in the laboratory. Biological characteristics and parameters were investigated and analyzed between the resistant strains and the susceptible strain.【Results】There were no significant differences in the durations of egg, larva and pupa, pupation rate, pre-oviposition period, longevity of male and female adults, average longevity and female rate of *B. dorsalis*. Egg hatching rate (68.33%) and adult emergence rate (93.73%) of the

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medium-level trichlorfon resistant strain (Tri-M) was significantly lower than those of the susceptible strain (SS), which were 88.33% and 97.93%, respectively, and those of high-level trichlorfon resistant strain (Tri-H), which were 86.67% and 98.21%, respectively. Compared with the fecundity of SS (864.61 eggs laid per female) and Tri-H (750.70 eggs laid per female), the fecundity of Tri-M decreased to 630.87 eggs laid per female. All strains had coincidently daily fecundity dynamics of females, indicating that the oviposition peak periods come in a short time after sexual maturity of females. The oviposition peaks of the resistant strains were observed earlier than that of the susceptible strain. After the oviposition peak, fecundity decreased in a fluctuation. All the c values of equations to simulate adult survival rate dynamics of different strains were higher than 1, demonstrating that the equations fit to the I-type survival model. Adults of all strains could survive until the average longevity was reached. SS had the highest index of population trend ($I$=339.41), while Tri-H had a moderate ($I$=307.82) and Tri-M had the lowest index of population trend ($I$=175.79), indicating that the ascending of trichlorfon resistance of *B. dorsalis* populations was suppressed, and for Tri-M the suppression was stronger. The net reproductive rate ($R_0$) of Tri-M (217.49) was significantly lower than those of SS (327.89) and Tri-H (284.29), respectively. The intrinsic rate of increase ($r_m$) and finite rate of increase ($\lambda$) of the two resistant strains had no significant difference, but were much higher than those of SS, and the average generation period ($T$) of the two resistant strains was shorter than that of SS. The relative fitness of the high- and medium-level resistant strains was 0.8670 and 0.6633, respectively, significantly lower than that of SS. 【Conclusion】Under selection pressure of trichlorfon, there is significant decrease in the average generation period, egg hatching rate and pupation rate of Tri-M, while most of biological characteristics of the resistant strains of *B. dorsalis* have no significant change. Reproduction and development of populations of the trichlorfon-resistant strains are disadvantaged, while Tri-M is much more disadvantaged. Nevertheless, the resistant strains show better population growth potentials.

**Key words**: *Bactrocera dorsalis*; insecticide resistance; trichlorfon; biology; life table

自有机化学农药出现和广泛应用以来,在农林生产中化学防治成为了解决有害生物危害、降低农林业损失的重要手段(Sheets *et al*., 1979; Chen and McCarl, 2001; Popp *et al*., 2013)。在化学防治取得巨大经济效益的同时,其负面效应也逐渐显现,3R问题日趋严重(Hardin *et al*., 1995; Trumper and Holt, 1998; Gevao *et al*., 2000; Vontas *et al*., 2011)。许多研究表明,正是由于大量不合理使用化学杀虫剂导致了害虫抗药性的产生。自1946年首次发现黑腹果蝇 *Drosophila melanogaster* 对 DDT 产生抗性至2010年,已经发现超过600种昆虫对有机磷、氨基甲酸酯、拟除虫菊酯和烟碱类等多种杀虫剂产生了抗药性(Denholm *et al*., 2002; 高希武, 2012)。

在不同化学杀虫剂种类和使用强度的选择压力下不同种昆虫的生物学、生态学变化各有差异。棉铃虫 *Helicoverpa armigera*、小菜蛾 *Plutella xylostella*、嗜卷书虱 *Liposcelis bostrychophila*、淡色库蚊 *Culex pipiens*、斜纹夜蛾 *Spodoptera litura*、甜菜夜蛾 *Spodoptera exigua*、白纹伊蚊 *Aedes albopictus*、埃及伊蚊 *Aedes aegypti*、冈比亚按蚊 *Anopheles gambiae*、棉蚜 *Aphis gossypii*、苹果蠹蛾 *Cydia pomonella* 等昆虫的发育、寿命和生殖力等方面表现出不同变化,大部分情况下某些生物学特性被削弱,种群增殖能力、竞争能力有所降低或者明显降低(唐振华等, 1990; 吴益东等, 1996; 王进军等, 2001; Konno and Omoto, 2006; 庄华梅等, 2010; Konopka *et al*., 2012; Bara *et al*., 2014; Ishtiaq *et al*., 2014; Otali *et al*., 2014; Zaka *et al*., 2014)。而对含有 Bt 毒蛋白基因 *Cry1F* 的转基因玉米产生抗性的粘虫 *Spodoptera frugiperda* 却没有产生相对应的适合度代价(Vélez *et al*., 2014)。

桔小实蝇 *Bactrocera dorsalis* 是重要的水果害虫(梁光红等, 2003; Clarke *et al*., 2005; 黄素青和韩日畴, 2005),广泛分布于亚太地区(Fullaway, 1949; Christenson and Foote, 1960; Metcalf and Metcalf, 1992; Vontas *et al*., 2011; Wan *et al*., 2012),也在中国南方地区普遍发生并危害多种果蔬类作物果实,造成严重经济损失(谢琦和张润杰, 2005; 杨忠星等, 2009)。化学杀虫剂是防治桔小实蝇常用手段,在一些地区该虫已经对不同药剂产生了抗药性。台湾桔小实蝇对6种有机磷类、3种拟除虫菊酯类、1种氨基甲酸酯类和1种抗生素类杀虫剂产生了抗性(Hsu and Feng, 2000; Vontas *et al*., 2011)。潘志萍等(2005)、章玉苹等(2007, 2008)和 Jin *et al*. (2011)监测发现华南地区桔小实

蝇对敌百虫、高效氯氰菊酯和阿维菌素等均出现不同程度抗性,并且年度间存在变化。

目前,关于桔小实蝇抗药性种群生物学特性变化方面研究尚少。与敏感品系相比,抗高效氯氰菊酯的桔小实蝇种群趋势指数、净增殖率等降低,适合度为0.6474(章玉苹等, 2009);而二溴磷抗性品系生殖力降低,存活时间缩短(Fang *et al.*, 2011);抗多杀霉素种群内禀增长率降低,适合度为0.62(李培征等, 2014)。本文研究了桔小实蝇对敌百虫高抗和中抗性品系生物学变化,为杀虫剂使用和抗性治理提供科学依据。

# 1 材料与方法

## 1.1 供试昆虫

**1.1.1** 桔小实蝇饲养条件:饲养室温度25~28℃,相对湿度50%~70%,光周期14L:10D。使用由梁忆冰(1982)配方改进的人工饲料饲养幼虫。用酵母:蔗糖=1:1(m/m)的饲料饲养成虫。

**1.1.2** 桔小实蝇敏感品系(susceptible strain, SS):在室内不接触任何杀虫剂条件下使用人工饲料连续饲养69代。

**1.1.3** 桔小实蝇抗性品系:敌百虫高抗品系(high-level trichlorfon-resistant strain, Tri-H):虫源来自敏感品系,室内使用敌百虫连续处理成虫30代,获得的抗药性倍数为41.79倍的种群;敌百虫中抗品系(medium-level trichlorfon-resistant strain, Tri-M):虫源来自敏感品系,使用敌百虫隔代处理成虫35代,获得的抗药性倍数为19.20倍的种群。抗药性筛选方法参见章玉苹等(2009)。

我国的昆虫抗药性划分标准为抗性倍数在5~10倍时为低抗,10~40倍为中抗;40~160倍为高抗,160倍以上则为极高抗水平(王晨和颜忠诚, 2009)。本实验抗性品系昆虫抗性倍数均在对应抗性水平范围。

## 1.2 不同品系卵和幼虫的发育历期、孵化率、化蛹率测定

向自制卵收集器中倒入适量的橙汁并摇晃均匀,放置于装有处于产卵高峰的雌虫的养虫笼中,待成虫产卵1-2 h后取出收集器,并用小号毛笔将卵扫出接至装有人工饲料的塑料盒中,每隔6 h观察记录一次卵孵化数量。设3次重复,每重复接卵50粒。

卵孵化后,每天9:00和21:00观察并记录幼虫发育情况和数量,直至幼虫老熟、入沙土化蛹。以卵孵化至幼虫老熟跳出饲料的时间长度为幼虫历期,以化蛹数量除以孵化幼虫数量计算出化蛹率。

## 1.3 不同品系蛹的发育历期、羽化率以及雌雄比测定

将同一天跳出饲料的健康的桔小实蝇老熟幼虫放入装有湿沙的塑料杯中(相对含水量70%左右),待其化蛹后每6 h观察记录一次,计算蛹历期、羽化率和成虫雌雄性比。设3次重复,每重复观察50头。

## 1.4 不同品系成虫的寿命及产卵量测定

将羽化1 d后的健康桔小实蝇成虫转移到养虫笼中,提供水和人工饲料。羽化后5 d开始,向养虫笼中放入装有橙汁的卵收集器接卵,每天观察记录产卵量和死亡成虫数量,直至成虫全部死亡为止。设3次重复,每重复40对成虫。

## 1.5 数据分析和参数计算方法

桔小实蝇各虫期生长发育、存活、生命表参数的单因素方差分析以及模型拟合均使用SPSS19.0软件处理。

**1.5.1** 生命表参数:参照庞雄飞等(1984)、庞雄飞和梁广文(1995)、张孝羲(2002)的方法计算出桔小实蝇种群净增殖率(net reproductive rate, $R_0$)、内禀增长率(intrinsic rate of increase, $r_m$)、平均世代历期(average generation period, $T$)、周限增长率(finite rate of increase, $\lambda$)、种群趋势指数(index of population trend, $I$)等生命表参数。

**1.5.2** 成虫存活曲线:以桔小实蝇日龄为自变量,存活率为因变量获得存活曲线图,并用Weibull分布模型 $S_p(t)=\mathrm{e}^{-(\frac{t}{b})^c}$ 进行拟合。式中 $S_p$ 是年龄 $t$ 时的存活率,b为尺度参数,c为形状参数(殷万东等, 2012)。

**1.5.3** 相对适合度:基于净增殖率($R_0$),以敏感品系为参考,计算桔小实蝇抗性品系的相对适合度值(relative fitness, $R_f$)(王进军等, 2001),其公式如下:

$$R_f = \frac{\mathrm{Tri}\ R_0}{\mathrm{SS}\ R_0}。$$

式中Tri $R_0$ 和SS $R_0$ 分别为桔小实蝇抗性品系和敏感品系净增殖率;$R_f>1$,表明抗性品系繁殖力增强;$R_f<1$,则显示抗性品系存在适合度缺陷。

# 2 结果

## 2.1 桔小实蝇3个品系幼期的发育和存活

桔小实蝇SS,Tri-M和Tri-H 3个品系卵发育历期分别为45.83, 51.17和48.25 h,无显著差异;SS

和 Tri-H 品系孵化率较高，分别为 88.33% 和 86.67%；Tri-M 品系明显较低，为 68.33%（表 1）。抗性品系幼虫的发育历期和化蛹率均未发生变化，SS，Tri-M 和 Tri-H 品系发育历期分别为 123.17，125.50 和 124.25 h，化蛹率分别为 95.18%，96.90% 和 99.39%。蛹发育历期均在 232 – 242 h 之间，而 Tri-M 品系羽化率（93.74%）明显低于 SS 和 Tri-H 品系（分别为 97.93% 和 98.21%）。

**表 1　桔小实蝇敏感品系与抗敌百虫品系幼期发育历期与存活率**

**Table 1　Developmental duration and survival rate of the immature stages of susceptible and tyrichlorfon-resistant strains of *Bactrocera dorsalis***

| 品系 Strain | 卵 Egg | | 幼虫 Larva | | 蛹 Pupa | |
|---|---|---|---|---|---|---|
| | 发育历期(h) Developmental duration | 孵化率(%) Hatching rate | 发育历期(h) Developmental duration | 化蛹率(%) Pupation rate | 发育历期(h) Developmental duration | 羽化率(%) Emergence rate |
| SS | 45.83 ± 3.60 a | 88.33 ± 2.99 a | 123.17 ± 1.01 a | 95.18 ± 1.47 a | 231.78 ± 3.99 a | 97.93 ± 1.01 a |
| Tri-H | 48.25 ± 1.32 a | 86.67 ± 3.04 a | 124.25 ± 0.85 a | 99.39 ± 0.70 a | 242.28 ± 3.04 a | 98.21 ± 0.84 a |
| Tri-M | 51.17 ± 1.72 a | 68.33 ± 4.24 b | 125.50 ± 3.29 a | 96.90 ± 1.95 a | 239.44 ± 6.01 a | 93.74 ± 1.80 b |

SS：敏感品系 Susceptible strain；Tri-H：敌百虫高抗品系 High-level trichlorfon-resistant strain；Tri-M：敌百虫中抗品系 Medium-level trichlorfon-resistant strain. 下同 The same below. 数据为平均值 ± 标准误，同一列数据后具不同小写字母者表示在 0.05 水平上差异显著（Duncan 氏检验）；下表同。Data in the table are means ± *SE*. Different letters in the same column indicate significant difference at the 0.05 level（Duncan's test）. The same for the following tables.

## 2.2　桔小实蝇 3 个品系成虫的主要生物学参数

3 个品系桔小实蝇成虫产卵前期、雌虫寿命、雄虫寿命和雌雄平均寿命分别在 6.3 ~ 7.3，109.7 ~ 119.0，119.3 ~ 139.3 和 115.3 ~ 139.3 d，均未产生明显变化；但是，与 SS 品系（864.61 粒/雌）、Tri-H 品系（750.70 粒/雌）相比，Tri-M 品系雌虫产卵量显著降低至 630.9 粒/雌（表 2）。

**表 2　桔小实蝇敏感品系与抗敌百虫品系成虫产卵前期、寿命和产卵量**

**Table 2　Pre-ovipisition, longevity and average fecundity of the susceptible and tyrichlorfon-resistant strains of *Bactrocera dorsalis***

| 品系 Strain | 雌虫产卵前期(d) Pre-oviposition period | 产卵量(粒/雌) Fecundity (number of eggs laid per female) | 成虫寿命 Adult longevity (d) | | 平均寿命(d) Average longevity |
|---|---|---|---|---|---|
| | | | 雌 Female | 雄 Male | |
| SS | 7.33 ± 0.33 a | 864.61 ± 21.86 a | 119.00 ± 2.00 a | 124.67 ± 6.12 a | 127.33 ± 4.33 a |
| Tri-H | 6.33 ± 0.33 a | 750.70 ± 58.53 ab | 113.67 ± 8.84 a | 139.33 ± 9.40 a | 139.33 ± 9.4 a |
| Tri-M | 7.33 ± 0.33 a | 630.87 ± 13.06 b | 109.67 ± 4.70 a | 119.33 ± 2.40 a | 115.33 ± 2.4 a |

桔小实蝇 3 个品系雌虫日产卵量动态规律比较一致，均呈开始产卵后短时间内即进入产卵盛期，继而产量达到高峰，之后产卵量波动下降的趋势（图 1）。与 SS 品系相比（20 d），2 个抗性品系较早进入产卵高峰（Tri-H：13 d；Tri-M：13 d）。SS，Tri-M 和 Tri-H 高峰期产卵量分别为 28.8 粒/雌，28.6 粒/雌和 33.9 粒/雌。在产卵盛期后直到羽化后 61 d，SS 品系雌虫产卵量较高，Tri-H 次之，Tri-M 品系较低。

由图 2 可知，羽化后第 12 – 42 天，桔小实蝇抗性品系成虫存活率低于敏感品系，第 42 – 70 天 Tri-M 品系与敏感品系成虫存活率相近，Tri-H 品系则明显较低。SS 品系成虫存活率曲线更接近 S 型，Tri-M 品系更接近 SS 品系，Tri-H 品系存活率曲线类似较缓慢下降的双曲线。

对图 2 中成虫存活率动态进行拟合，建立了桔小实蝇 SS，Tri-M 和 Tri-H 品系虫存活动态方程（表 3）。3 个品系的方程参数 c 值分别为 2.600，2.233 和 1.675，均大于 1，因此，均为 I 型存活曲线基本模型。

**表 3　桔小实蝇敏感品系与抗敌百虫品系成虫的存活曲线拟合方程**

**Table 3　Equations to simulate adult survival rate dynamics of the susceptible and tyrichlorfon-resistant strains of *Bactrocera dorsalis***

| 品系 Strain | 回归方程 Equation | 相关系数 Correlation coefficient *r* |
|---|---|---|
| SS | $S_p(t) = e^{-(\frac{t}{67.484})^{2.600}}$ | 0.9985 |
| Tri-H | $S_p(t) = e^{-(\frac{t}{62.336})^{1.675}}$ | 0.9975 |
| Tri-M | $S_p(t) = e^{-(\frac{t}{68.153})^{2.233}}$ | 0.9945 |

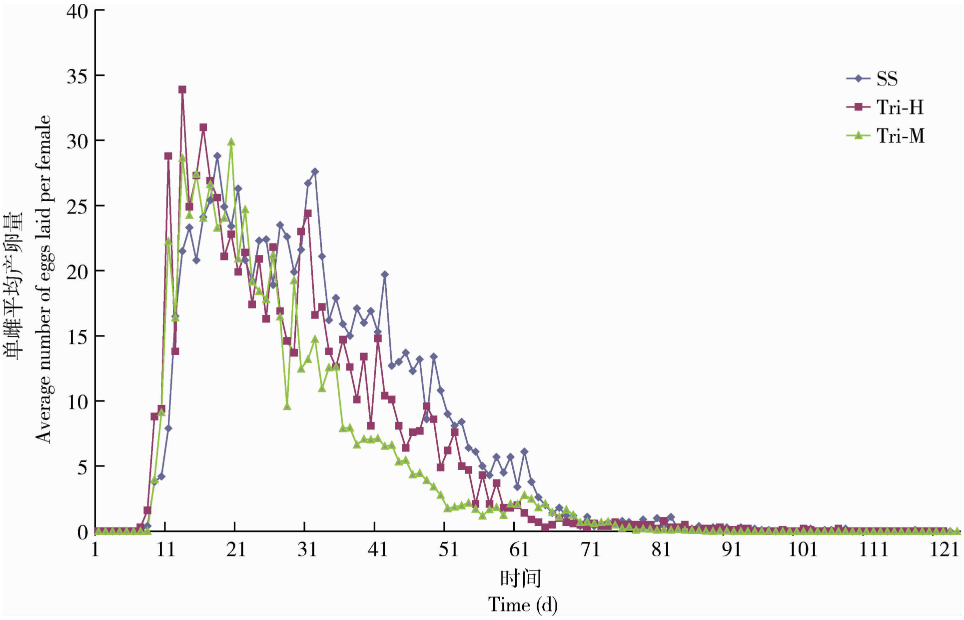


图 1 桔小实蝇敏感品系与抗敌百虫品系雌虫日产卵量动态

Fig. 1 Fecundity dynamics of female adults of the susceptible and trichlorfon-resistant strains of *Bactrocera dorsalis*

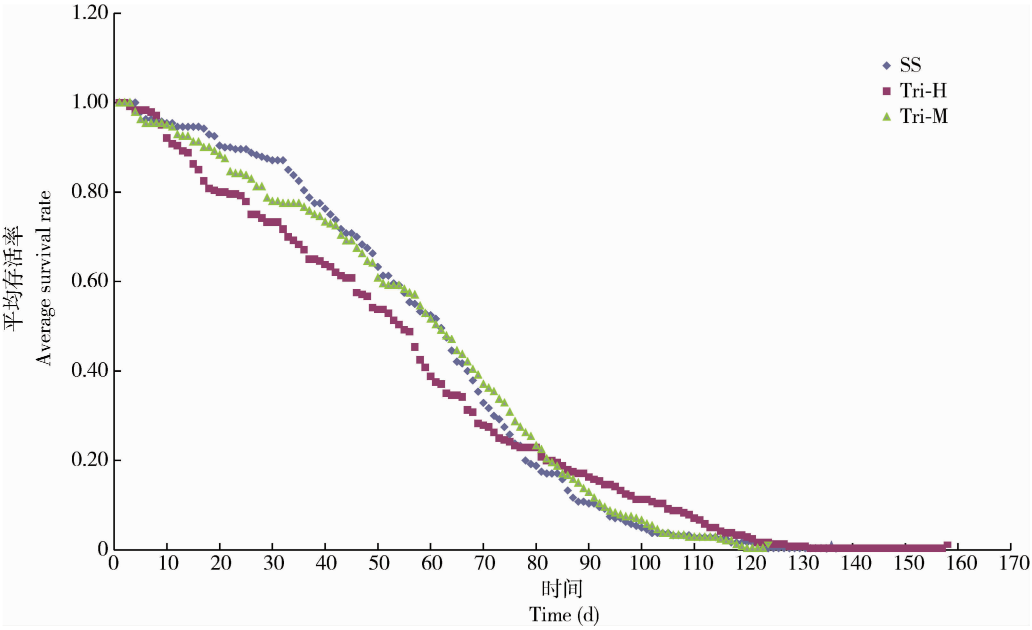


图 2 桔小实蝇敏感品系与抗敌百虫品系成虫存活率动态

Fig. 2 Survival rate dynamics of the susceptible and tyrichlorfon-resistant strains of *Bactrocera dorsalis*

表明在实验室的理想环境下这 3 个品系成虫绝大部分个体能达到其平均寿命，主要是因衰老而死亡。

**2.3 桔小实蝇 3 个品系实验种群生命表及其适合度**

SS, Tri-M 和 Tri-H 品系成虫雌虫比率分别为 0.4768，0.4489 和 0.4847，没有显著差异（表 4）。从种群趋势指数（$I$）可以看出最高的是 SS 品系，为 339.41，其次为 Tri-H 品系（$I=307.82$），最小为 Tri-M 品系（$I=175.79$）。这表明对敌百虫产生抗药性抑制了桔小实蝇种群的增长，而 Tri-M 品系抑制程度更大，种群世代增长能力更弱。

由实验种群净增殖率（$Ro$）计算结果可知，SS 和 Tri-H 品系净增殖率较高，分别为 327.89 和 284.29，Tri-M 品系显著低于以上 2 个品系，为 217.49。SS，Tri-H 和 Tri-M 内禀增长率（$r_m$）分别为 0.1966，0.2196和 0.2184，周限增长率（$\lambda$）分别为 1.2173，1.2457 和 1.2442，世代历期分别为 29.50 d，25.70 d

**表 4　桔小实蝇敏感品系与抗敌百虫品系实验种群生命表**

**Table 4　Life table of test population of the susceptible and tyrichlorfon-resistant strains of *Bactrocera dorsalis***

| 虫态 Developmental stage | 作用因子 Impact factor | 存活率 Survival rate | | |
|---|---|---|---|---|
| | | SS | Tri-H | Tri-M |
| 卵 Egg | 不孵化 Non-hatching | 0.8833 ±0.0299 a | 0.8667 ±0.0304 a | 0.6833 ±0.0424 b |
| 幼虫 Larva | 生理死亡 Recessive death | 0.9518 ±0.0147 a | 0.9939 ±0.0070 a | 0.9690 ±0.0195 a |
| 蛹 Pupa | 不羽化 Non-emergence | 0.9793 ±0.0101 a | 0.9821 ±0.0084 a | 0.9374 ±0.0180 b |
| 成虫 Adult | 雌虫比率 Proportion of females | 0.4768 ±0.0245 a | 0.4847 ±0.0340 a | 0.4489 ±0.0264 a |
| | $F^*$ 概率 Probability of standard fecundity | 0.4323 ±0.0109 a | 0.3754 ±0.0293 ab | 0.3154 ±0.0065 b |
| | 标准卵量 Standard fecundity | 2 000 | 2 000 | 2 000 |
| 种群趋势指数 Population tendency index ($I$) | | 339.41 | 307.82 | 175.79 |

同一行数据后具不同小写字母者表示在 0.05 水平上差异显著(Duncan 氏检验)。Different letters in the same row indicate significant difference at the 0.05 level (Duncan's test).

**表 5　桔小实蝇敏感品系与抗敌百虫品系实验种群参数和相对适合度**

**Table 5　Population parameters and relative fitness of the susceptible and tyrichlorfon-resistant strains of *Bactrocera dorsalis***

| 品系 Strain | 净增殖率 Net reproductive rate $R_0$ | 内禀增长率 Intrinsic rate of increase $r_m$ | 周限增长率 Finite rate of increase $\lambda$ | 平均世代历期(d) Average generation period $T$ | 相对适合度 Relative fitness $R_f$ |
|---|---|---|---|---|---|
| SS | 327.89 ±3.07 a | 0.1966 ±0.0051 b | 1.2173 ±0.0062 b | 29.50 ±0.75 a | 1.0000 |
| Tri-H | 284.29 ±30.76 a | 0.2196 ±0.0059 a | 1.2457 ±0.0074 a | 25.70 ±0.61 b | 0.8670 |
| Tri-M | 217.49 ±2.12 b | 0.2184 ±0.0033 a | 1.2442 ±0.0041 a | 24.65 ±0.36 b | 0.6633 |

和 24.65 d(表 5)。两抗性品系 $r_m$ 和 $\lambda$ 间则无显著差异,且均显著大于 SS 品系,世代历期则显著缩短,完成一个世代所需时间相对更短。抗敌百虫品系内禀增长率增大,种群增殖潜力更高。以种群净增殖率为标准,分析结果表明:与 SS 品系相比 2 个抗性品系相对适合度分别为 0.8670 和 0.6633,均有所降低。

## 3　讨论

本文通过研究抗敌百虫桔小实蝇高抗、中抗品系与敏感品系之间的生物学特性,发现敏感品系与抗性品系的卵、幼虫和蛹的发育历期、化蛹率、产卵前期、寿命和雌虫比率均无变化,且各品系桔小实蝇成虫均能达到其平均寿命;中抗品系的卵孵化率和蛹羽化率显著降低。一般来讲,具抗药性的昆虫生物学会发生改变。斜纹夜蛾抗甲维盐品系的卵孵化率更低而幼虫发育历期变长(Zaka *et al*., 2014)。抗苄氯菊酯的白纹伊蚊和埃及伊蚊成虫寿命和孵化率发生显著变化(Bara *et al*., 2014)。苹果蠹蛾的抗药性品系幼虫和蛹发育历期均变短(Konopka *et al*., 2012)。德国小蠊 *Blattella germanica* 抗药性品系幼虫发育历期、幼虫存活率、产卵前期、成虫寿命也发生显著变化,且抗性品系每个龄期均比敏感品系短(Ang and Lee, 2011)。

本文研究结果还显示,桔小实蝇 3 个品系的雌虫有比较一致的日产卵量动态,但敏感品系雌虫总产卵量明显高于抗药性品系,产卵盛期日产卵量也比抗性品系高,说明抗性品系的生殖力比敏感品系要低。这与棉蚜抗丁硫克百威品系、桔小实蝇抗二溴磷品系和斜纹夜蛾抗甲维盐品系生殖力研究结果相似(Konno and Omoto, 2006; Fang *et al*., 2011; Zaka *et al*., 2014)。不同昆虫种类、杀虫剂类型甚至实验条件下抗药性昆虫生物学特征会表现出不同的变化,这些变化没有一定的规律性,但是基本会在一定程度上反映出抗药性削弱了昆虫的生物潜能。虽然,本研究明确了该实蝇敌百虫抗药性品系生物学特征发生了变化,但其内在机制尚不清楚,如从遗传和基因水平探讨可能会获得深入的解释。在其他一些昆虫中已开展了一些这方面的探讨。例如抗拟除虫菊酯类杀虫剂的菜花露尾甲 *Meligthes aeneus* 的 *CYP6BQ23* 基因表达量会随着抗性水平的提高而提高(Zimmer *et al*., 2014),抗氯氟氰菊酯的家蝇 *Musca domestica* 的抗药性基因 *kdr* 的基因频率会随 $LD_{50}$值的升高而升高(冷培恩等, 2009)。

生命表方法广泛应用于分析、研究不同因子对害虫种群动态的影响,并能对害虫的种群数量发展趋势进行预测,以便制定相应的防治策略与方法(庞雄飞和梁广文, 1995)。从桔小实蝇 3 个品系种群数量增长来看,抗药性品系种群趋势指数、净增殖

率明显低于敏感品系,尤其以中抗品系为甚,说明其种群增长受到抑制。在不考虑种群世代历期的情况下,抗性品系相对适合度均有所下降,最低的中抗品系只有 0.6333,表明抗性品系种群表现繁殖不利。该结果与对桔小实蝇抗高效氯氰菊酯、多杀菌素和二溴磷品系以及棉铃虫抗氰戊菊酯品系的研究结果相似(吴益东等, 1996; 章玉苹等, 2009; Fang *et al*., 2011; 李培征等, 2014)。综合考虑桔小实蝇种群的数量发展、存活率、产卵量和世代历期,本文研究所用抗性品系的内禀增长率均显著高于敏感品系,说明该抗性品系种群比敏感品系种群有更高的增殖潜力。但是,基于世代净增殖率获得的相对适合度值表明该虫抗敌百虫品系生物学适合度却下降了。因此,采用哪种指标评价抗药性品系的适合度更科学值得进一步探讨。

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